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DIGITAL AUDIO BROADCASTING:

Measuring techniques and coverage performance for a medium power VHF single frequency network

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Summary

The advent of digital formats such as CD has created demand for uniformly high audio quality from radio. In order to provide such high-quality stereo reception, a Digital Audio Broadcasting (DAB) system capable of reliable reception in vehicles and on portables has been developed by the European EUREKA 147 Project. As a VHF frequency allocation would appear most suitable for the introduction of terrestrial broadcasting of DAB in the United Kingdom, the BBC is undertaking a major experiment to test the EUREKA DAB system and to generate data to allow efficient planning of its transmitter network. A network of four, 1 kW e.r.p., VHF transmitters has been installed to cover the London area in England. This Report describes the experimental programme and the rationale and measurement techniques behind it.

The results show a wide-area coverage from the transmitter network which is in reasonable agreement with computer predictions. This indicates that the current transmitting and receiving equipment (built to the EUREKA specification) is operating in the way that would be expected from theoretical studies and simulation. The results also provide quantitative values which can be used for coverage prediction and for international co-ordination of services. Finally, the performance of the system demonstrates a number of the benefits of the EUREKA DAB system for mobile and portable reception.

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1. INTRODUCTION

FM sound broadcasting in Band II was designed as a high-quality system and can provide excellent sound quality. But the advent of digital formats, such as CD, has created a demand for a similar uniformly high audio quality from radio. Also, listeners' requirements of a radio system have changed. People now demand high-quality and rugged audio reception (in stereo) in vehicles and on portable radios. To enable high-quality stereo reception by all types of receiver, a Digital Audio Broadcasting (DAB)* system capable of providing reliable reception in vehicles and by portable receivers has been developed by the EUREKA 147 Project.

There was a need to design a system that could be used in many different countries and situations. The EUREKA DAB system was designed to work for both terrestrial and satellite broadcasting in a range of frequency bands. This is ensured by providing three modes:

- Mode 1 was designed for wide-area, terrestrial broadcasting at VHF frequencies — such networks are likely to be extensively used in Europe.

- Mode 2 was designed for local-area, terrestrial broadcasting, at frequencies up to 1.5 GHz. Such networks may be used in some countries in Europe and in other geographical regions, such as Canada, where the new 1.5 GHz (L-band) allocation is available.

- Mode 3 was designed for satellite broadcasting at frequencies up to 3 GHz. This may be particularly attractive in large countries, and for continental coverage.

In the UK, a VHF implementation for terrestrial broadcasting of DAB is preferred for the following reasons:

- A national SFN can be economically implemented at VHF with large transmitter spacings and using existing broadcasting transmitter sites.

- L-band is unlikely to be allocated for broadcasting in the UK until the year 2007. Even then, as it is primarily intended for satellite broadcasting, it may be difficult to make efficient use of the limited spectrum for separate satellite and terrestrial DAB in the same coverage area.

- The terrestrial propagation of signals, over terrain typically found in the UK and into buildings, is generally better at VHF than L-band.

The BBC is undertaking a major experiment to test the EUREKA DAB system and to generate data to allow efficient planning of its transmitter network. This article describes this experimental programme and the rationale behind it.

2. PLANNING FOR DIGITAL SYSTEMS, MOBILE AND PORTABLE RECEIVERS

EUREKA DAB is explicitly designed to provide a reliable service for mobile and portable receivers. This introduces a number of issues which must be addressed in the system design and coverage planning.

- Generally, digital modulation systems have abrupt failure characteristics. This means that the received audio signal can change from high quality to total failure with only a small change in input signal level to the receiver.

- Mobile and portable receivers use omni-directional antennas at a low height. Consequently the path from the transmitter to the antenna is rarely unobstructed and the receiver obtains no discrimination against multipath from other objects.

- Portable receivers are usually used in buildings; this means that the additional loss and variability in signal level within buildings must be quantified.

* DAB has been registered as a trademark by one of the members of the Eureka 147 project.

3. DESCRIPTION OF THE EUREKA DAB CODING AND MODULATION SYSTEM

EUREKA DAB is based upon a coded-orthogonal-frequency-division-multiplex (COFDM) modulation system[1]. COFDM modulation uses a large number of RF carriers each of which is QPSK modulated at a relatively slow symbol rate. The carriers are spaced in frequency such that, as each carrier is demodulated, there is no interference from data carried on adjacent carriers, i.e. they are orthogonally spaced. The digital audio signals are protected with convolutional coding and the resulting data is distributed across all the carriers in the RF band. Consecutive data samples are also separated in time. As a result, the audio data can still be recovered at the receiver even if some of the carriers can not be demodulated owing to anomalous propagation effects (such as multipath).

In the EUREKA DAB system, the problem of the abrupt failure characteristic typical of digital systems, is addressed by the introduction of unequal error protection of the audio signal. This process is described in more detail in Ref. 2.

However, two additional features are needed to improve the performance of the system in multipath environments:

- A wide bandwidth (significantly greater than the few hundred kHz currently used for FM broadcasting) is needed to reduce the effects of the short-delay multipath that cause the flat fading problems. Effectively this introduces frequency diversity into the system; and a wide enough bandwidth is needed to ensure sufficient decorrelation between the different components for the diversity to be effective. To retain spectral efficiency with this bandwidth, a number of programmes are bundled together.

- At the transmitter, each QPSK symbol is transmitted for longer than necessary to fulfil the requirements for orthogonal frequency spacing of the carriers. The extra time is known as the **guard interval**. At the receiver, an appropriate portion of this extended symbol (chosen to restore the orthogonal frequency relationship) is demodulated. The result is that echoes with a delay of less than the guard interval do not produce inter-symbol interference. The power in this multipath signal can then be used constructively to aid demodulation.

An extra advantage of this system is that simultaneous reception of the same information from more than one transmitter is possible. The delayed signals from the more distant transmitters will simply look like multipath. This can be used to provide more reliable coverage of an area as it introduces spatial diversity. The term network gain is commonly used to refer to this improvement in coverage when more than one transmitter is received. It also allows all the transmitters in a network to use the same frequency – thus providing excellent spectrum efficiency. This mode of operation is known as the Single Frequency Network (SFN).

4. EXPERIMENTAL WORK

A new system with these additional features poses new challenges for efficient frequency and service area planning. For example, the SFN concept allows a choice to be made between serving an area (be it a city or a country) with a small number of high-power transmitters or a larger number of low-power transmitters. Or, the rugged digital system allows much lower transmitter powers to be used – but reliable coverage now depends on being able to quantify and predict the amount of signal variation which would be encountered by mobile or portable receivers.

For this reason the BBC has installed a network of four, 1 kW, VHF, Band III, DAB transmitters around London. With a population of around 10 million people (18% of the UK population) this provides a suitable test-bed for the system. The purpose of the experiment is to test extensively the DAB system in a realistic environment and gather coverage data to allow more accurate planning of the BBC's proposed transmitter network. It also provides a platform for experiments on components of a DAB transmitter network and on receiver implementation.

Field strength predictions and measurements are normally made for 50% (median) location values. If the median field strength in a particular area is equal to the minimum value for an acceptable service, the area is deemed to be served (assuming that no interference or other effects need to be considered). In the case of an analogue system there will still be a service to considerably more than 50% of locations, but with reduced quality. For a digital service such as DAB, however, this would not be the case. The transition from perfect quality to audio muting will occur over relatively few dBs, depending on the system characteristics. In view of the rapid degradation in digital systems near the failure point, it is necessary to provide an adequate field strength in a high percentage of locations. A figure of 99% has been suggested for mobile reception. To achieve this, the

median field strength must be increased by a suitable **location correction factor** (50 – 99% correction factor in this case).

The value of the correction factor is important in planning a DAB service. In general, a small value is desirable since it implies a lower median field strength, and thus lower transmitter power. Since the DAB signal uses a much wider bandwidth than FM, there is expected to be a degree of frequency diversity. This has the effect of reducing variations in the field strength due to terrain effects, multipath, etc. Consequently, the location correction factor is reduced. The extent of this reduction was the first object of study.

If an area is simultaneously served by several transmitters in an SFN, there is expected to be a degree of spatial diversity, resulting in a further reduction in signal variation. The second purpose of this work was to quantify the improvement.

Finally, the amount of reduction in signal level for reception in buildings was examined.

4.1 Transmitting system

For the experiment, four DAB transmitting stations were installed. Sites already used for broadcasting conventional TV and Radio programmes were selected; these allowed the experimental signal to be radiated from an antenna mounted at a representative height above the ground. The locations of the sites selected are shown in Fig. 1 *and were:*

- **Crystal Palace** The main transmitter for UHF TV transmissions to London, located in the south of London.
- **Wrotham** The main transmitter for VHF FM Radio transmissions to London, located to the east of London.
- **Reigate** A transmitter situated on the ridge of hills to the south of London and used to transmit TV programmes at UHF to towns to the south of London.
- **Alexandra Palace** A transmitter situated to the north of London and originally used to transmit TV programmes at VHF to London.

In each case provision was made to be able to transmit an e.r.p. of 1 kW from each transmitter. In addition, the Crystal Palace transmitter was specified to be able to transmit an e.r.p. of 10 kW, if required. The radiation pattern of the Crystal Palace transmitter was arranged to be approximately omni-directional. The

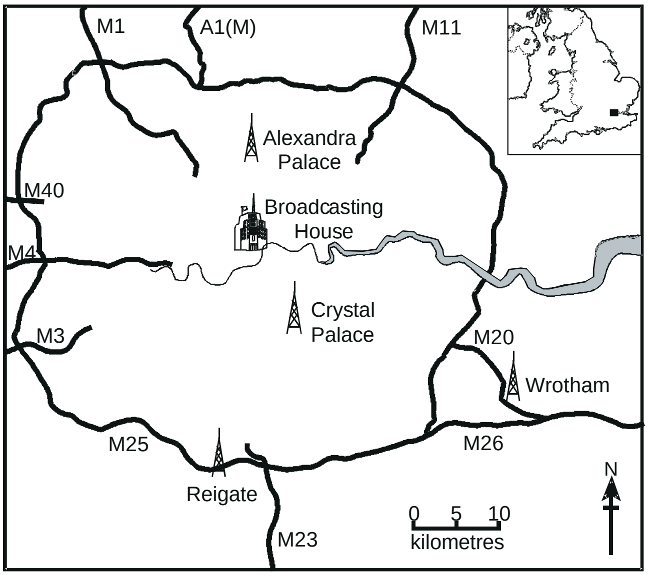

Fig. 1 - Location of the London DAB transmitter.

other three transmitters had patterns which directed most of the power towards London. This allowed the SFN concept to be tested.

For the first stage in the experiment the DAB signal was generated at the Crystal Palace transmitter and distributed at UHF to the three surrounding sites. This allowed simple transmitters consisting only of frequency translation and amplifying equipment to be installed at the other sites. As the network moves towards a pilot DAB service for London, more sophisticated distribution methods are being installed.

4.2 Measuring system

For both mobile and portable measurements a DAB receiver, signal level measuring equipment and a computer were installed in an estate car. The survey vehicle (Fig. 2) which was specially equipped for DAB measurement, had a low roof line so as to be

Fig. 2 - DAB survey vehicle.

representative of normal car reception. A Band III receiving antenna was fitted in the centre of the roof to give a response as close as possible to omni-directional. An additional antenna was fitted to provide signals to a positioning system and mobile telephone.

The system has been designed to allow measurements to be made of position, received signal strength and DAB system performance, up to 10 times a second whilst the vehicle is on the move. This data is analysed later. The approach allows the large amounts of data gathered to be processed efficiently and effectively.

4.2.1 Hardware

The vehicle (using the system outlined above) is fitted with a third generation DAB receiver and a Rohde & Schwarz ESVB receiver to measure field strength. Audio material from the DAB receiver is played through the car radio system; this allows subjective assessment of the audio quality to be made by the engineers. The following additional information is recorded on a portable PC:

- Violations of the audio scale factor cyclic redundancy checksum (CRC) and occurrences of muting are recorded as an objective measure of audio performance. This is important for two reasons: firstly, it takes into account the combination of degradations due to low signal strength, long-delay (and hence interfering) DAB signals, and non-DAB interference such as man-made noise. Secondly, it allows the performance of the signal to be measured without the need to transmit specific test data — thus the audio programme can continue to be broadcast.

- DataTrak and GPS positioning systems are fitted which give positional information to around 50 m accuracy. However, experimental experience has shown that the positional information becomes unreliable when the vehicle is in heavily forested and some dense urban areas.

In addition, an oscilloscope and spectrum analyser are provided to assist the engineer making the measurements. The former allows the impulse response (derived from the DAB receiver) to be displayed, thus showing the number and relative magnitude of the signals being received. The later allows CW interferers and man-made noise to be identified. The resulting block diagram for mobile measurements is shown in Fig. 3.

Considerable care has been taken to screen the experimental hardware as it has been found that radiation from this equipment (particularly the DAB receiver) can significantly limit the performance of the system. It is anticipated that this problem will be reduced in later versions of DAB receivers which incorporate custom ICs.

In cases where measurements of portable reception quality were to be made inside a house, the antenna was taken into the house, but the rest of the equipment was left in the vehicle. For measurements in buildings, two types of receiving antenna were used. The first consisted of a folded-dipole antenna and was chosen to provide a well-matched antenna for reliable measurement of signal strength, Fig. 4. The second

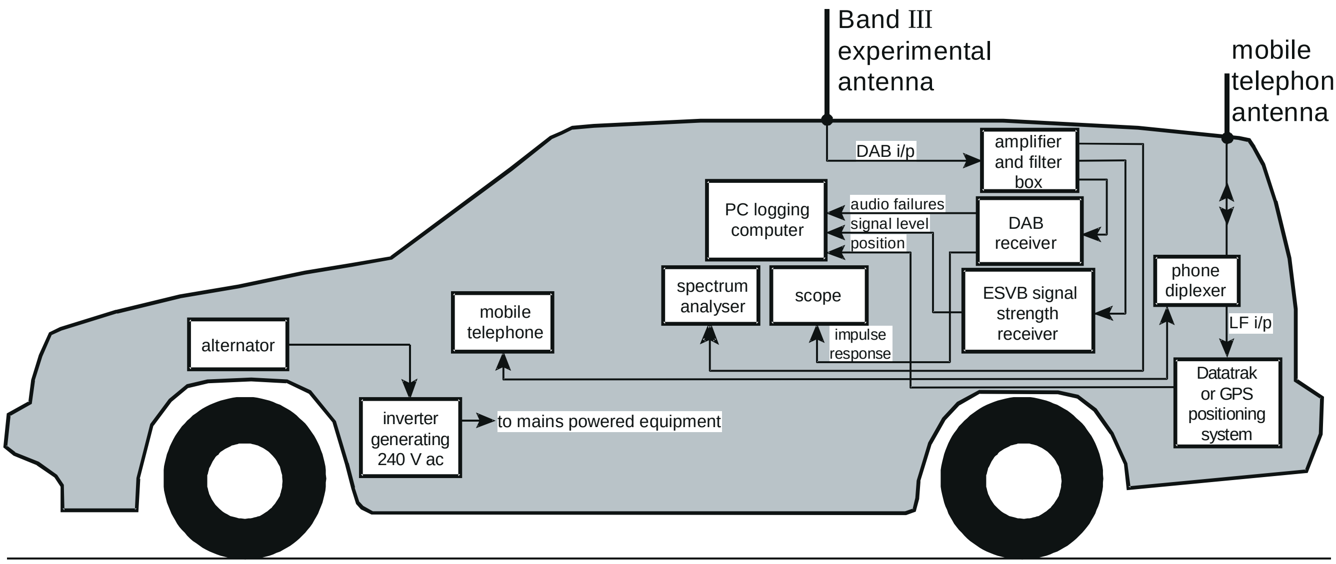

Fig. 3 - Mobile measuring equipment.

Fig. 4 - Field strength measurement in a house.

was an antenna installed on a metal box of approximately the same size as a conventional radio receiver. This was used for making measurements of expected signal quality in buildings, Fig. 5.

In both cases, a large number of measurements in each area were made so that valid signal statistics could be calculated — even for relatively small percentages of locations.

4.2.2 Logging and analysis software

In order to meet the survey data acquisition requirements of the high-power DAB field trials, a new logging program has been developed. The program runs on a 386 type computer (or better) under Microsoft 'Windows' version 3.1 and represents an easy-to-use graphical interface for the operator. At the heart of the program is a fully configurable system for defining the devices and interfaces that are being used to gather data. A number of interface cards are supported, including RS232, GP-IB and DMA (parallel interface). There is no need to write specific software to communicate with a particular type of measurement device. So long as it has an interface that is supported by the data logging software, a suitable communication link between computer and measurement instrument can be configured. This enables the software to be used for a large number of different data-gathering functions.

Once a configuration has been established, it may be saved together with the default information that is to be stored in the data file. This information includes the parameters of the system for which the data was gathered, the date and time and the name of the operator.

In addition to the measured data, calibration information, survey and project-related details are

Fig. 5 - Rod antenna mounted on a mock, portable DAB receiver used for measuring subjective requirements for coverage.

recorded. The information is stored in a file format directly compatible with the suite of analysis programmes.

During data acquisition, the data is displayed to the user as it is gathered, giving a reliable indication of the performance of the system under measurement, Fig. 6. The same display format is available to show previously-logged data files for comparison.

Software has also been written to perform analysis of survey data gathered during field trials. The data files are processed by a suite of programs which have been developed in C and written so that each program performs a separate operation that is useful in the analysis procedure. A full audit trail is maintained of the processes performed on the data.

A series of programs may be run on a survey data file to produce the desired analysis. Each individual program performs a simple function on the data, such as sorting it, finding various statistics, displaying it, etc. The required analysis is performed by assembling these routines in the desired order. This provides a very flexible analysis tool. The results can be output to wordprocessor or spreadsheet applications. Each program has a wide variety of options so that individual programs may be easily tailored to do a specific task in the analysis procedure.

4.3 Experimental methodology

4.3.1 Survey areas

The first priority in the experimental work was to measure the signal level and system performance with individual transmitters (each at 1 kW e.r.p.). Only then could the effects of multiple transmitters be examined. This would simultaneously provide information about the performance of the system and allow comparisons between the measured and predicted signal levels in an area.

The area that was expected to be covered by the transmitter network was large. Obtaining reliable statistics for the signal level and audio quality available at 99% locations required a large number of measurements in each small area. It was clearly impractical (and unnecessary) to survey every area in such detail. Therefore predictions of the expected coverage were obtained and used to target ‘interesting’ areas. In general, these were areas which were expected to be most marginal. However, in the early stages of the experimental work, an exception was made and relatively wide areas were surveyed but taking only a few roads in each. This was required to identify any system problems which might have

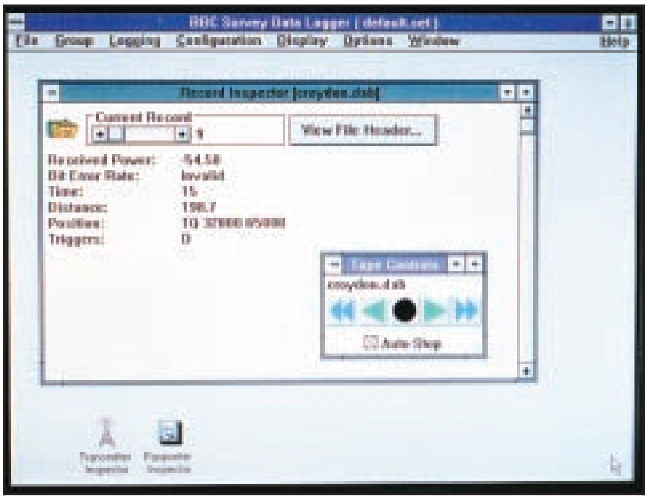

Fig. 6 - DAB logging software.

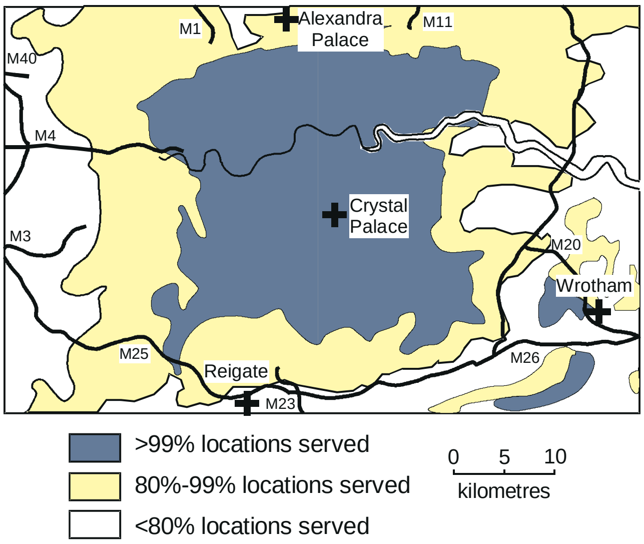

Fig. 7 - Predicted coverage of the Crystal Palace transmitter.

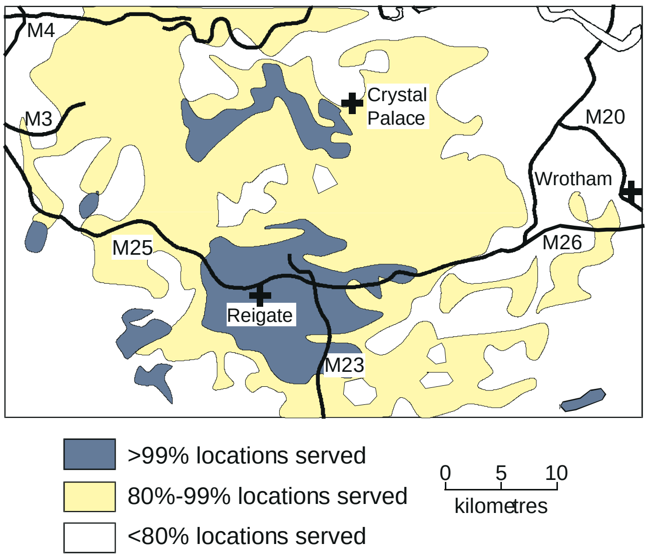

Fig. 8 - Predicted coverage of the Reigate transmitter.

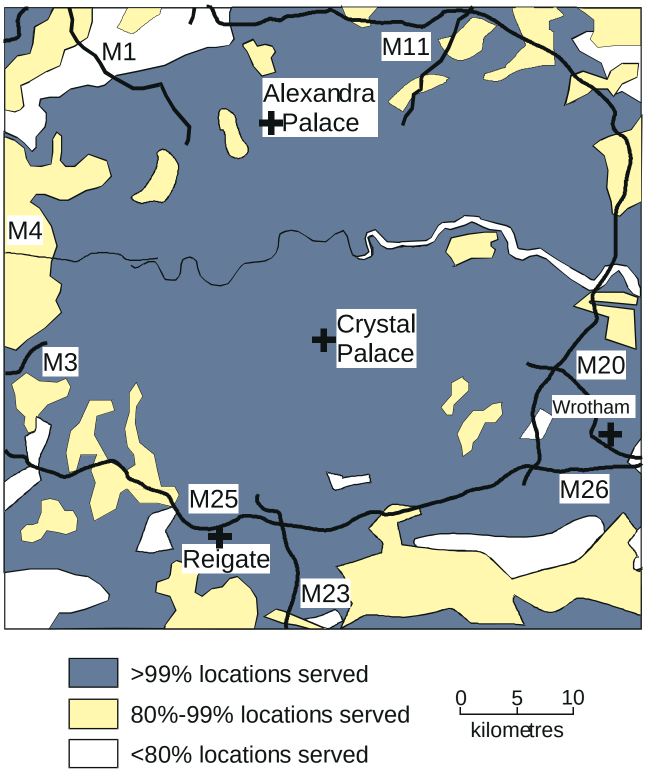

Fig. 9 - Predicted coverage of the total network.

occurred in areas which were expected to be served — and hence would not otherwise have been surveyed.

For the predictions, a version of the BBC field strength prediction method, which was developed for planning conventional, analogue TV and FM Radio coverage, was used[3]. However, modifications have been made to allow for the different characteristics of the digital signal, and the low gain and height of the receiving antenna installation[4]. The predicted coverage for two of the individual transmitters and the total network is shown in Figs. 7, 8 and 9. These predictions are presented in terms of the expected percentage of locations served in each area. To the west of London, the relatively flat ground results in an even reduction in signal level with distance from the transmitter. However, to the south of London there is a region of very swift changes in expected coverage which is caused by an area with many small hills and valleys. A wide range of types of ground clutter are also encountered — the centre of London being a dense urban area, whereas further out there are suburban and rural areas.

Measurements were also made in domestic houses. The purpose of this work was to make measurements of the building penetration loss in domestic houses and to obtain a first estimate of the coverage required by listeners. In this case, the distribution of houses was constrained to those in the predicted service area which were made available by volunteer BBC staff; this therefore limited the selection available.

4.3.2 Measurement and analysis techniques

4.3.2.1 Mobile work

Having targeted areas of particular interest, they were surveyed in detail. For this work, the area was divided into 500 m by 500 m squares and measurements made in a number of these squares in an area. The use of these squares allowed easy comparison of measured and predicted results, as the prediction algorithms currently have a maximum resolution of 500 m.

A number of forms of analysis were performed:

- The mean and standard deviation of the measured field strengths measured in each square was found. The predicted field strength was also calculated.
- The measured field strength and the receiver status were compared to find the minimum field strength for correct operation of the receiver.
- The objective measure of audio quality derived from the DAB receiver was compared with the subjective result recorded by the engineer in the vehicle.

4.3.2.2 Portable work

In this work, measurements of signal level were made in the 500 m by 500 m square where the house was located, immediately outside the house and in various ground floor rooms inside the house. The results could then be analysed to find the average building penetration loss and the variation in signal level within a house.

4.3.3 Equipment set-up

The logging system was set to record:

Time	from its internal clock
National Grid Reference (NGR)	from the positioning system
Received Power	from the ESVB
Audio scale factor CRC errors (a coarse measure of audio quality)	from the DAB receiver

Readings were initially triggered by elapsed time at the rate of one per second. The ESVB receiver was set for an integration time of 10 ms. This meant that each reading would be averaged over about 10 DAB symbols, so that variations in signal level within a symbol period (and across a null) were averaged out. The receiver filter was set to 1.5 MHz, in line with the

bandwidth of the DAB signal, and the centre frequency was set to 226.25 MHz, the centre frequency of the experimental transmissions.

After some initial experiments the arrangement was re-configured to trigger each 96 ms COFDM frame. Measurements were then made more frequently, allowing greater detail of the fast-fading statistics to be recorded. The integration time of the ESVB was correspondingly reduced. Synchronisation of the measurement time to the COFDM frame meant that measurements of signal strength during the null symbol could be avoided.

4.4 Future improvements

A number of improvements to the experimental techniques and equipment can be suggested as a result of our recent experiences. The simplest changes relate to changes in the measurement vehicle to reduce or eliminate the amount of equipment requiring mains power. A move to an entirely 12 V powered arrangement is envisaged in the near future. However there are two somewhat longer-term changes that are being considered.

Measurements of the **total** received signal strength can be made satisfactorily using a conventional measuring receiver or a specialist DAB receiver. The only detailed requirement for DAB is that measurements should not be made during the null symbol. However, measurements of the signal strength from an **individual** transmitter will be required to assess the effect of modifying an SFN. That is, it is highly desirable to measure the field strength of one transmitter in an SFN on its own. This would be used in an operational environment when the benefit of adding a fill-in transmitter was being considered.

This measurement can be achieved in a number of ways; one such method is by using the TII. The power in the comb of carriers radiated in the null symbol could be calculated. The delay of the signal can be found from the difference in phase between adjacent carriers in the comb, and the transmitter can also be uniquely identified. The only problem with this method is that measurements could only be made between 5 and 10 times per second (for a mode 1 signal). However, for most purposes, this may be satisfactory when used in conjunction with a measure of total signal strength made more frequently.

The second consideration is that a computer display on a map overlay of the DAB performance would greatly improve the targeting of operational survey work. This option is also being considered.

5. RESULTS

5.1 Calibration

Two calibration issues were considered. Firstly, confidence was needed that the calibration factor arising from the antenna and amplifier gain, feeder loss and voltage-to-power conversion had been correctly measured and calculated. To do this, measurements were made at a test point which had a line-of-sight path to a transmitter; the results were then compared with predictions.

Secondly, confidence was needed about the repeatability of field strength measurements. For this purpose, three sets of measurements were made over a short test route with the vehicle travelling at different speeds and in a different direction around the route. The results for each run were compared and showed differences that were significantly less than 1 dB.

In each case, the results provided confidence that reliable and repeatable results could be obtained.

5.2 Coverage area of transmitters

5.2.1 Coverage of individual transmitters

The coverage of a transmitter was measured in two ways. Firstly, the subjective quality of the received audio signal was noted. Three categories were used to record this data; areas where the audio signal was unimpaired, areas where the signal was unintelligible and the areas in between. Secondly, the objective results of the signal levels and receiver status were analysed as the number of CRC errors and muting events within the 500 m by 500 m squares. The squares were classified into one of three categories:

Unimpaired:	No more than one CRC error and no mutes within square
Marginal:	Two or more recorded CRC errors, but no mutes
Impaired:	Muting occurs within square

As a single isolated error may not be audible, a square is only deemed to be marginal if two or more errors were logged. Mutes, on the other hand, always last for at least one second. Thus the minimum criteria for a square to be deemed impaired was just one mute. It should be noted that this is a very onerous criteria, as a single mute can be caused by a small tunnel or bridge, or a high level of man-made noise from a single building. Fig. 10 shows that a good agreement is obtained between the subjective and objective measurements.

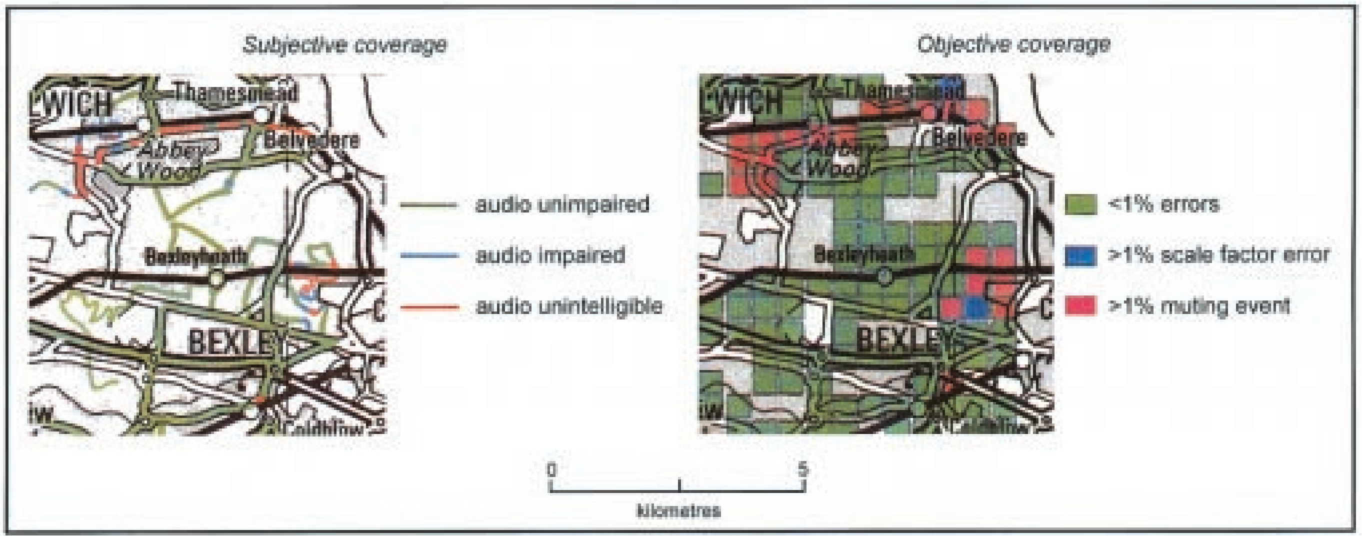

Fig. 10 - Comparison of subjective and objective measures of mobile coverage.

The results of the objective measurement of audio quality for two of the individual transmitters are shown in Figs. 11 and 12 (see pages 10 and 11 respectively). Whilst the whole area has not been surveyed, comparisons with predictions in Figs.7 and 8 show results that are similar to those predicted. Some trends can be identified in the differences. Coverage in rural areas was generally found to be better and coverage in dense urban areas slightly worse than predicted. This is probably because the BBC prediction programme has been optimised for prediction to suburban areas. The system performance in some urban areas was also found to be affected by man-made noise. In a small percentage of locations, high levels were observed.

Space does not permit a detailed comparison between the predicted and measured results. However, the general conclusion is that the DAB signal covers a somewhat larger area than predicted. Fig. 13 *(see page 12)* compares the median values of measured and predicted field strength. This shows a trend at low field strength of the prediction programme under-estimating the field strength. The difference probably explains the difference in coverage areas.

5.2.2 Coverage of the full network

Initial measurements have targeted areas in which the coverage was expected to be marginal. Findings so far confirm the large expected benefit in system performance arising from the simultaneous reception of several signals.

An example of the effect is shown in Figs. 14 to 20. Fig. 14 *(see page 12)* shows terrain in the south west of greater London, which is on the edge of the service area from both the Crystal Palace and Reigate transmitters. The area is also interesting as it contains relatively flat terrain to the north and a more hilly ridge of land in the south. The predicted coverage of the area from the individual transmitters and for the whole network is shown in Figs. 15 to 17 *(see pages 13)*. These show that a significant benefit from network gain can be expected here but, even so, the area is only expected to be marginally served.

The area was also measured in each of the three conditions. The results are shown in Figs. 18 to 20 *(see page 14)*. These show a somewhat better coverage measured than predicted. They also show that the expected benefit of anticipated network gain is realised in practice. As a result, the only place which was not found to be covered was a small valley in the hilly district. (This part is also documented as being badly placed for analogue signal reception.) Detailed coverage results for the whole network have been made and similarly show that the predicted coverage has been obtained.

5.2.3 Network gain

The transmitter and logging arrangement has allowed the fast-fading statistics and the correlation between signals from different transmitters to be explored in more detail. The correlation is, of course, an important quantitative measure of the network gain that can be expected.

To enable this, the transmitters were put in a state where they were switched on and off each COFDM frame. The correlation between signals received quasi-simultaneously from different transmitters could be measured. This effect is demonstrated in Figs. 21 to 23 *(for Figs. 21 and 22 see page 15, for Fig. 23 see page 16)*. Fig. 21 shows the received signal level from the Crystal Palace and Reigate transmitters and the case when both are switched on. These measurements

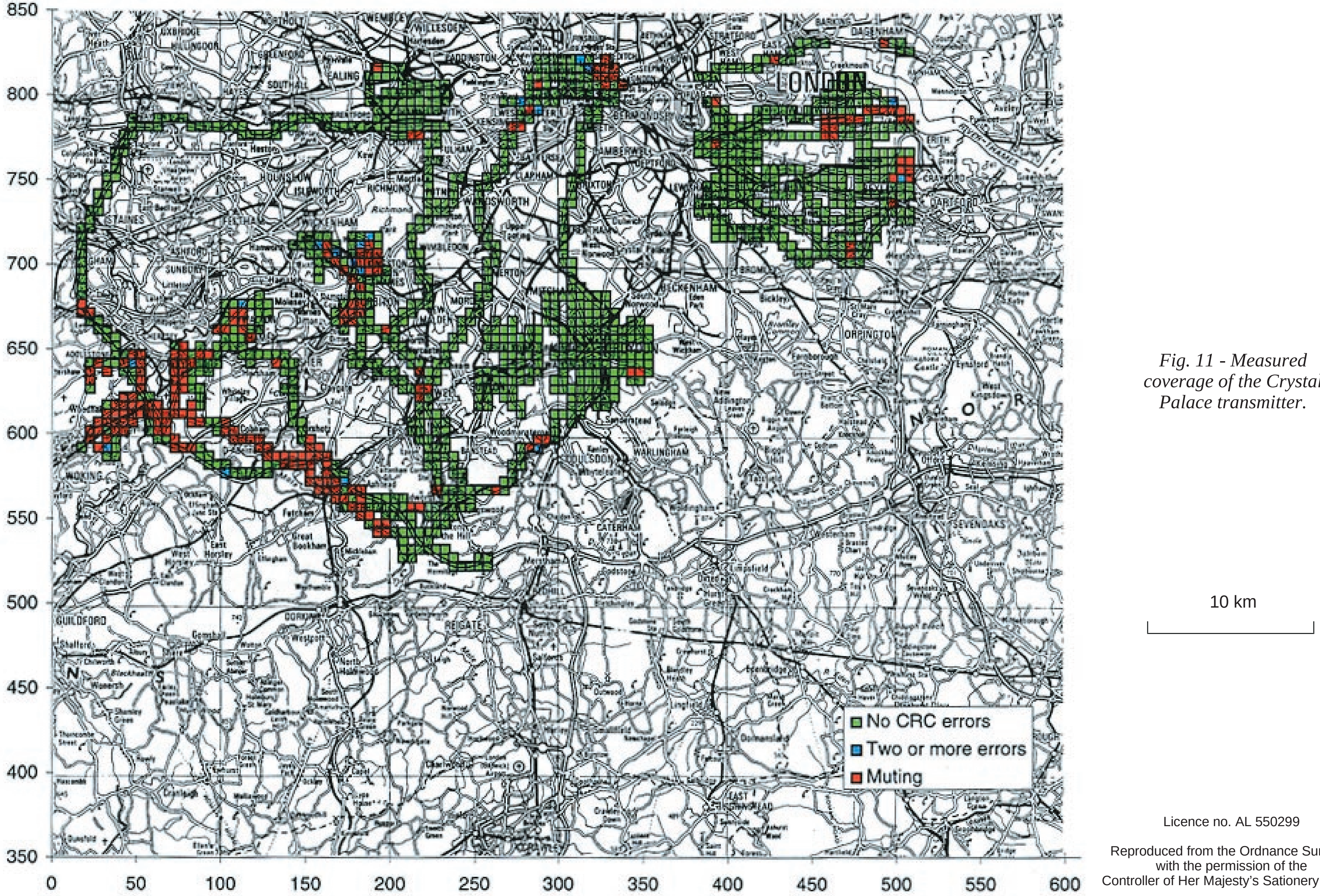

Fig. 11 - Measured coverage of the Crystal Palace transmitter.

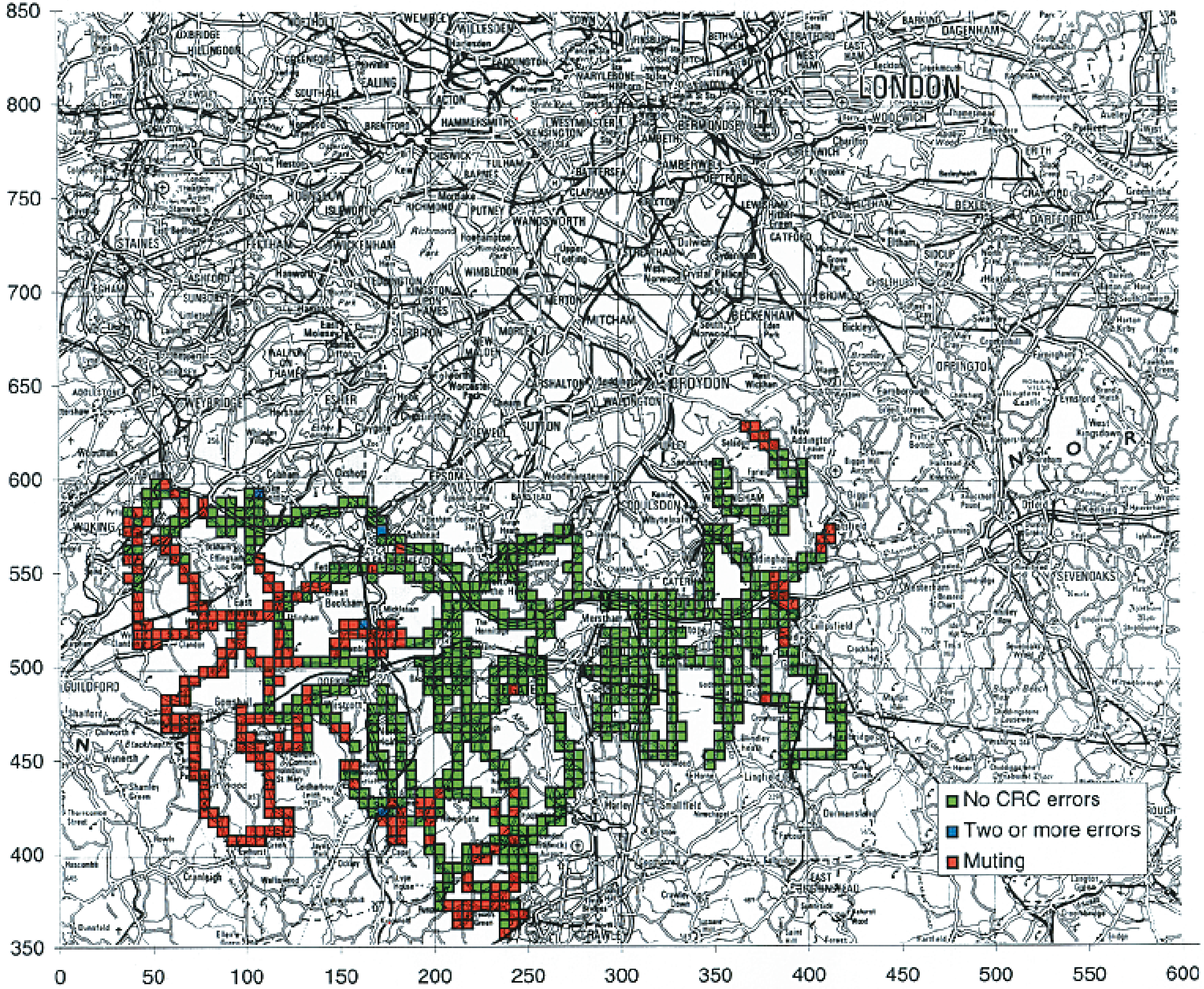

Fig. 12 - Measured coverage of the Reigate transmitter.

10 km

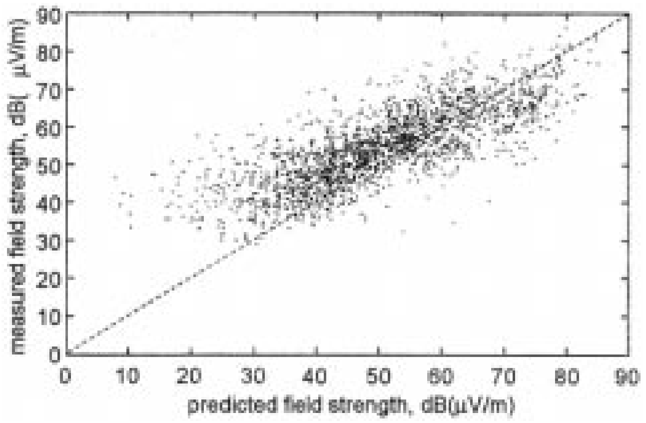

Fig. 13 - Comparison of measured and predicted field strength.

were made along approximately 100 m of road. The superposition of the fast-fading (local multipath) variation on the slow-fading variation can be seen. As it is the slow-fading component of the signal variation in a local area which is particularly important in the consideration of network gain, the fast-fading component was removed by calculating a moving average across a number of measurements. The slow-fading component is shown in Fig. 22. It can be seen that there is significant decorrelation between the signals from the two transmitters. The effect on the network gain at the 99% locations level can be found by calculating the cumulative distribution; this is shown in Fig. 23. At the 99% locations point, Fig. 23 shows that the performance of the system with both transmitters on is about 6 dB better than the performance with only the Crystal Palace transmitter. This result is particularly important, as the Reigate transmitter is producing a median field strength in the area which is considerably lower than that from Crystal Palace.

5.3 Local-area variations in signal strength

The measured results were analysed to find the local-area variation in the slow-fading component of the signal. For this purpose, measurements gathered in each 500 m by 500 m square over the area were analysed to find the median signal levels and the standard deviation of the variation. Sample areas were checked to ensure that the signal distribution was a reasonable approximation to log normal.

The standard deviation of the local area variations in signal level were averaged for different terrain types. The information about terrain types was obtained from a clutter database of the area which categorises each square by the percentage of the area covered by buildings. This percentage provides an approximate indication of rural, suburban, urban and dense urban areas. In averaging the standard deviations the results

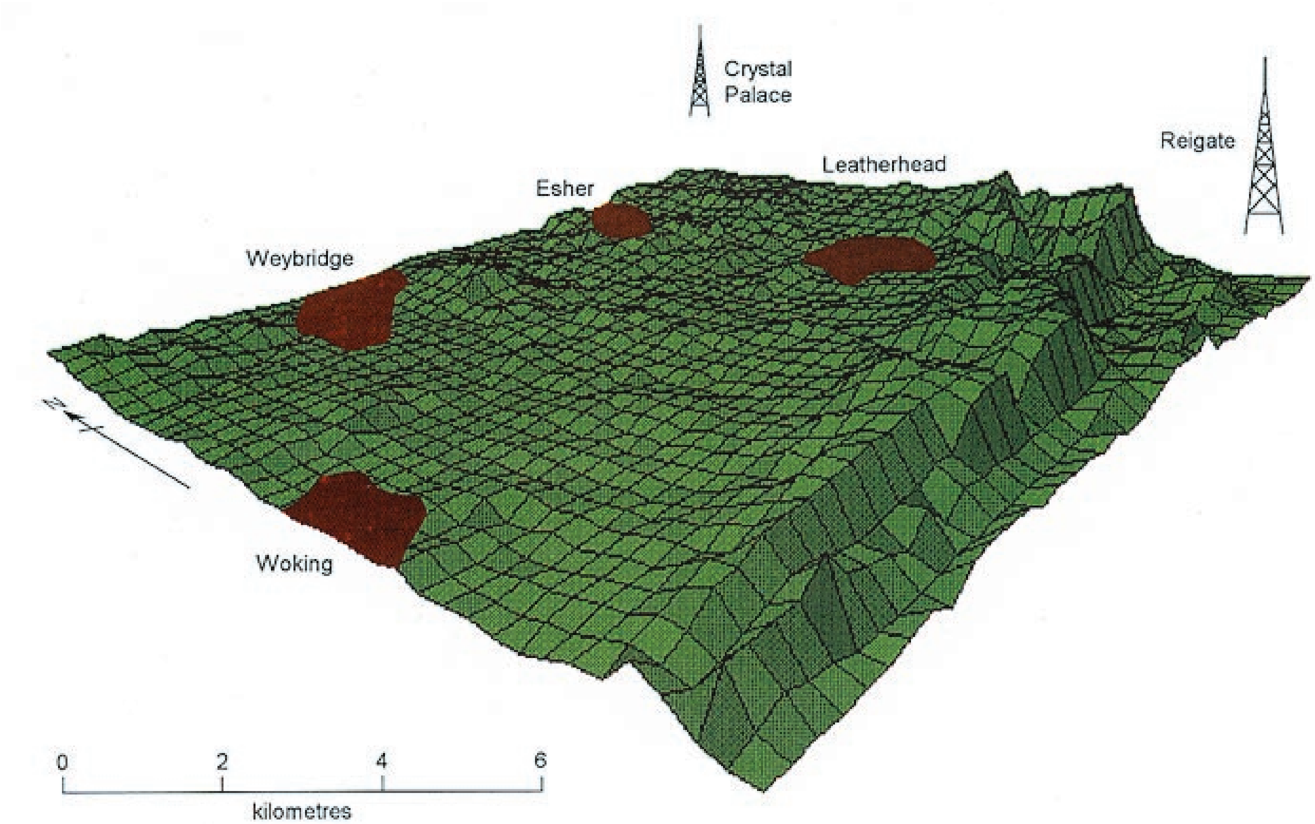

Fig. 14 - Terrain around Woking and Leatherhead area (Vertical scale exaggerated).

Table 1:
Standard deviation of the signal variation in local areas.

Amount of building cover (%)	Number of areas in the category	Weighted average standard deviation (dB)
100	151	4.3
90	215	4.1
80	167	4.1
70	144	4.0
60	126	3.7
50	148	4.2
40	141	4.1
30	105	3.8
20	150	4.0
10	181	4.0
occasional	509	4.2
0	170	3.9
Total	2217	4.1

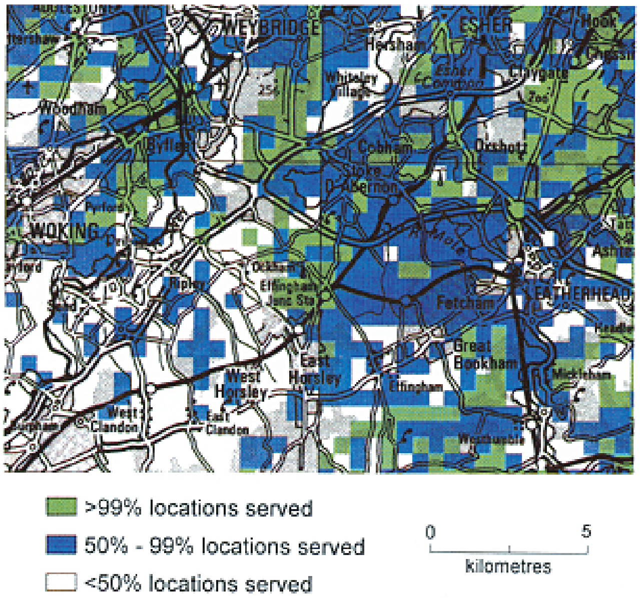

Fig. 16 - Predicted coverage of the Reigate transmitter.

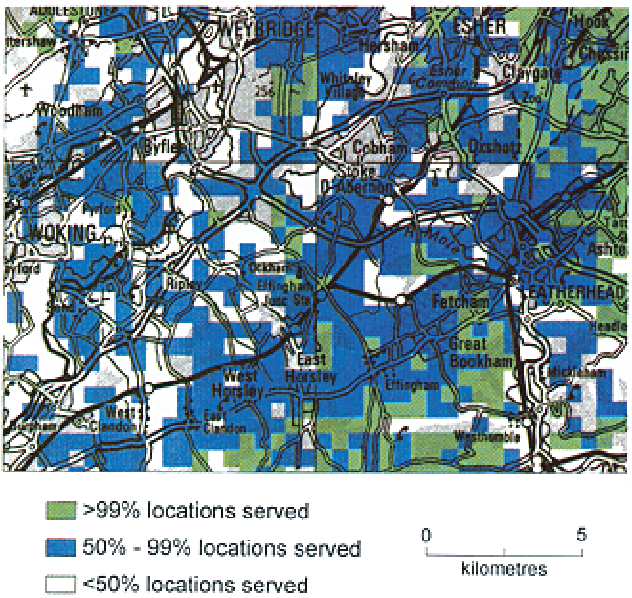

Fig. 15 - Predicted coverage of the Crystal Palace transmitter.

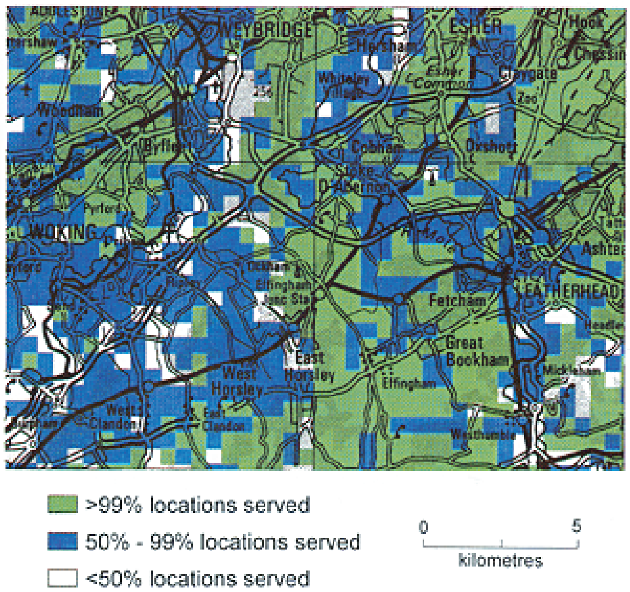

Fig. 17 - Predicted coverage of Crystal Palace and Reigate transmitters.

were weighted by the number of samples recorded in each area. The results are summarised in Table 1.

The results for over 2200 areas showed an average standard deviation of 4.1 dB. The spread in the values of standard deviation is shown in Fig. 24 *(see page 16)*.

The results show (as expected) significantly less signal variation than occurs with narrowband systems, for which a value of 9 dB is implicitly assumed in the ITU[5]. This confirms a result which has been measured using low-power transmitters in an earlier network. In that experiment, measurements were made in the same area (from the same transmitter) of the signal variation using a wideband and narrowband signal. The results, Fig. 25 *(see page 16)*, showed standard deviations of signal variation of 9 dB and 5 dB for the narrowband and wideband signals respectively.

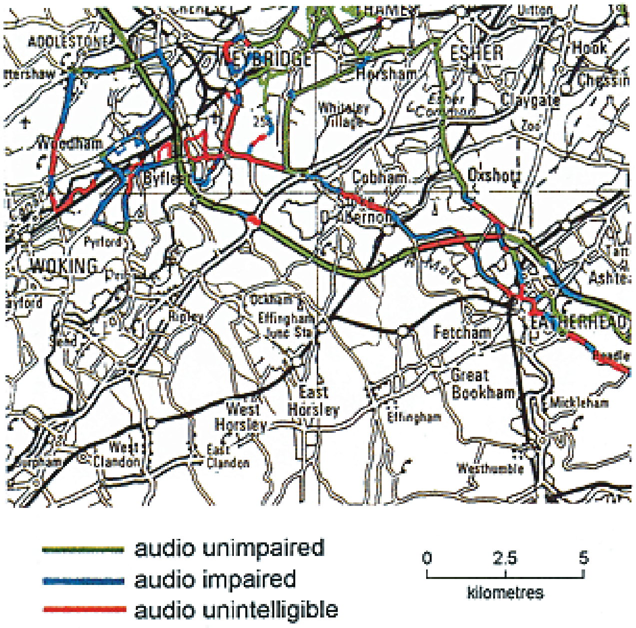

Fig. 18 - Measured coverage of the Crystal Palace transmitter.

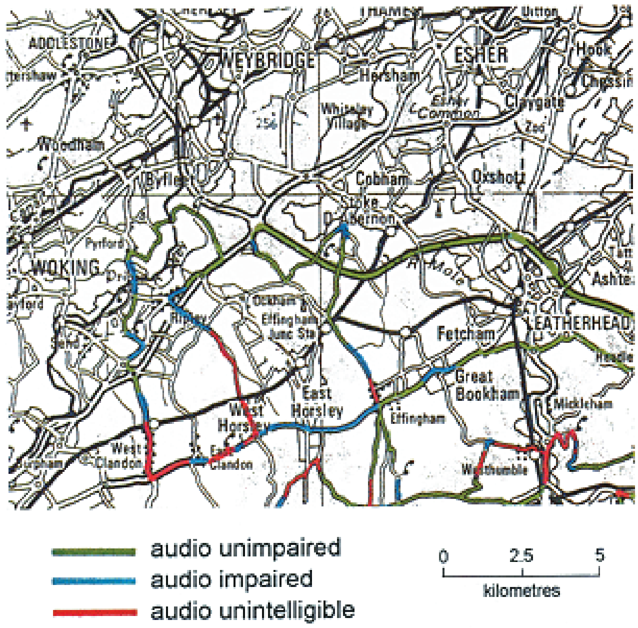

Fig. 19 - Measured coverage of the Reigate transmitter.

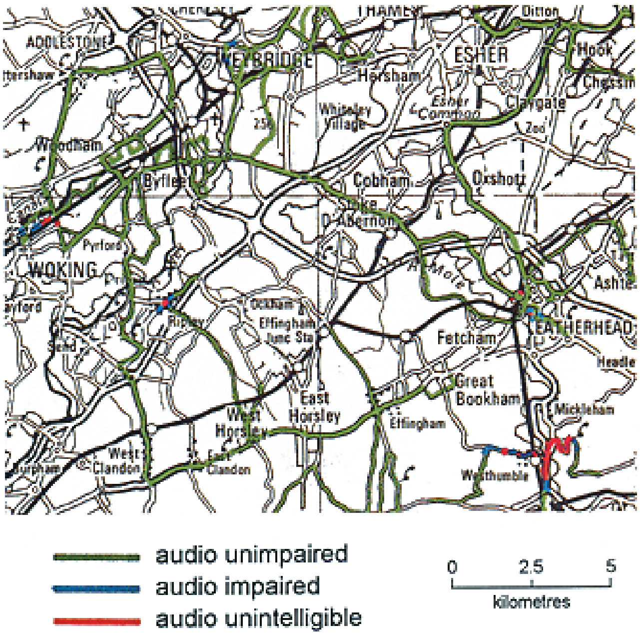

Fig. 20 - Measured coverage of the Crystal Palace and Reigate transmitters.

The second point to note from these results is that the standard deviation is slightly lower than has been measured before[6]. The reasons for this are still being studied in detail, but the most likely are:

- that the current measurements concentrate more on the slow-fading component of the signal and consequently a longer power-integration period is used than before; and
- a wider variety of terrain has been surveyed.

The second point is important, in that earlier experiments were confined to a relatively small area, much of which was located in relatively undulating terrain. The effect of this is to increase the amount of signal variation in a small area. The current work explores a wider range of terrain types.

The third point to note from the results in Table 1, is that the amount of ground clutter appears to have relatively little effect on the amount of signal variation. This is perhaps an unexpected result. Once again, this subject is still being studied: but it is possible that any variations due to differences in ground clutter are being swamped by differences in the amount of terrain undulation.

5.4 System performance results

The purpose of this work was to determine the failure field-strength for the DAB receiver from the mobile measurements. To do this, measurements were analysed to determine:

- The maximum signal strength in an area where the audio was not badly degraded
- The minimum signal strength in an area where the audio was degraded

The results showed a wide variation in field strength with a mean failure field strength of around 40 dBμV/m. This result is slightly higher than the value sometimes assumed for DAB planning; however, the current measurement arrangement is known to suffer from higher levels of man-made noise

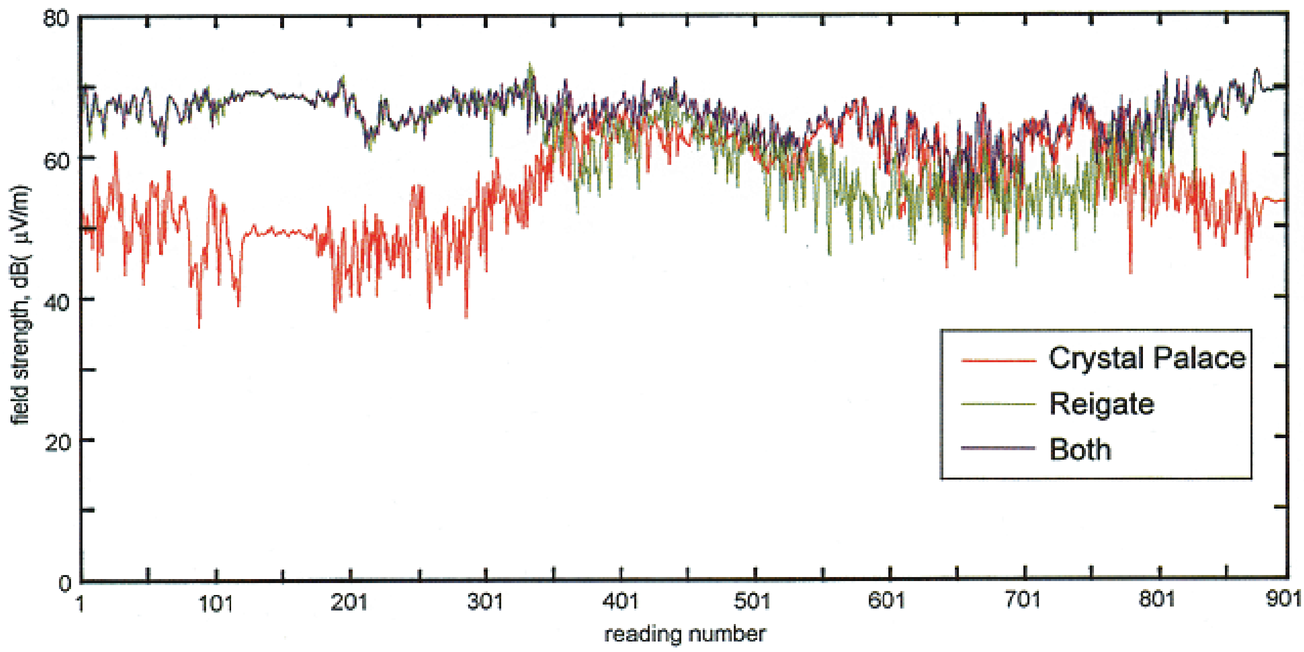

Fig. 21 - Field strength versus distance Epsom Downs test route (not averaged).

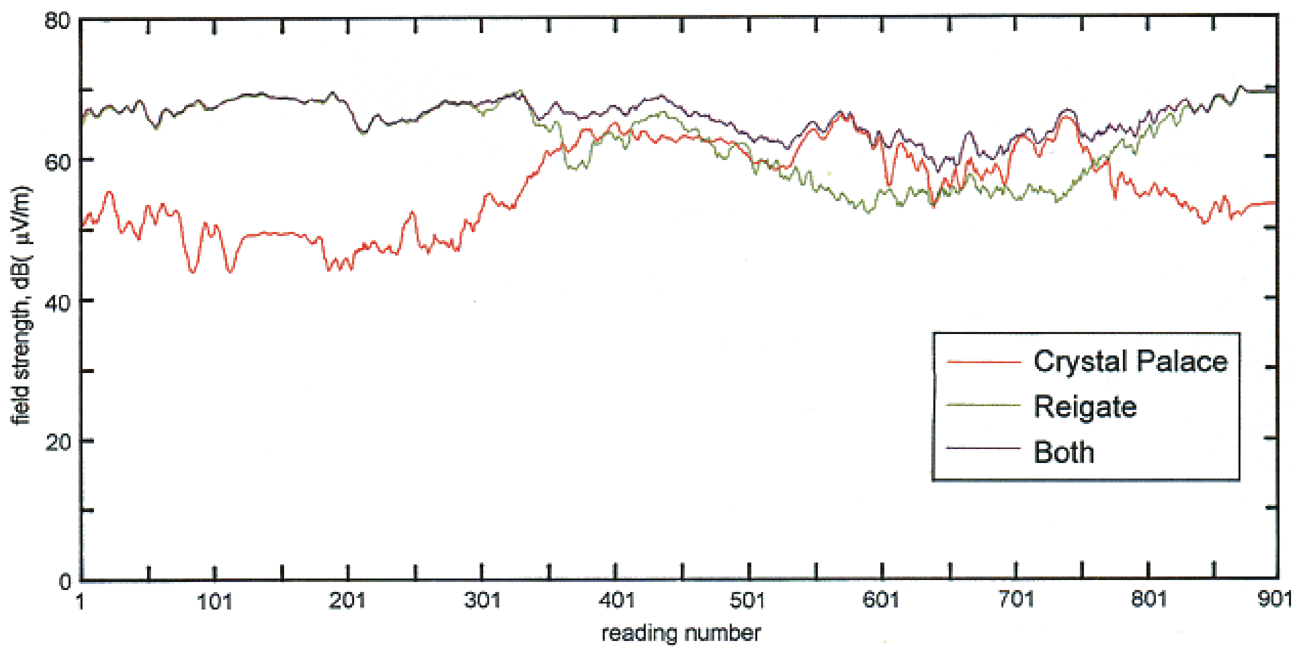

Fig. 22 - Field strength versus distance Epsom Downs test route (moving averaged).

than would be expected in a domestic arrangement. Considerable care has been taken in the measuring vehicle to screen the relevant equipment; but even so, a significant cause of the man-made noise is the 3rd generation DAB receiver itself.

5.5 Measurements in buildings

5.5.1 Objective measurements

An important value for planning coverage to portable receivers in buildings is the building penetration loss. That is, the difference between the signal level inside the building and the level that would have been received in the same place if the building were not there. This is found by measuring the signal statistics outside the building, on the side nearest the transmitter, and the signal statistics inside. The difference in median values can then be found.

A total of 39 building losses have been measured. The first 26 were measured using low-power transmitters

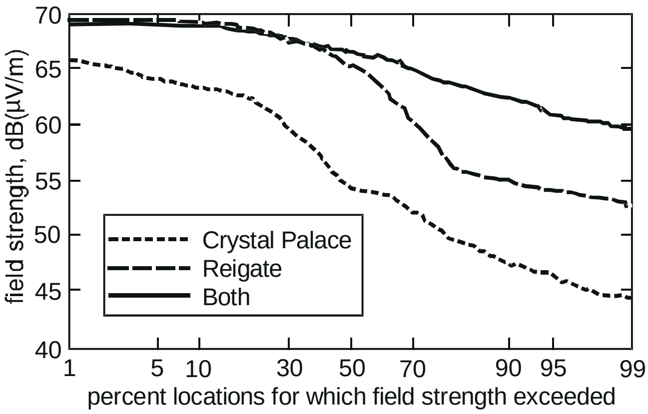

Fig. 23 - Cumulative distribution for Epsom Downs test route (moving average data).

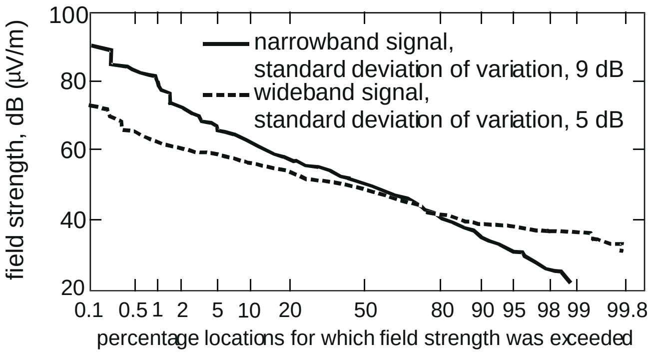

Fig. 25 - Differences in amounts of signal variation for wideband and narrowband systems.

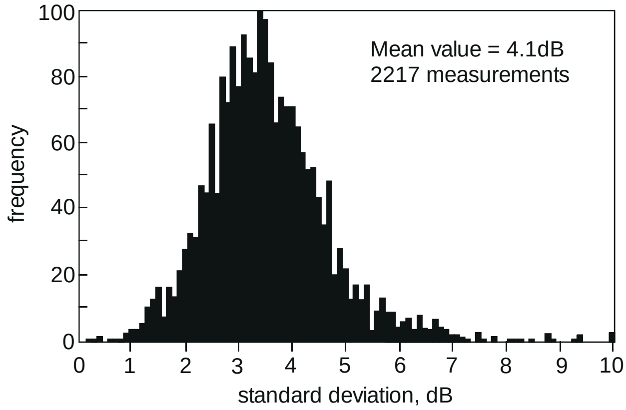

Fig. 24 - Variation of field strength in a local area.

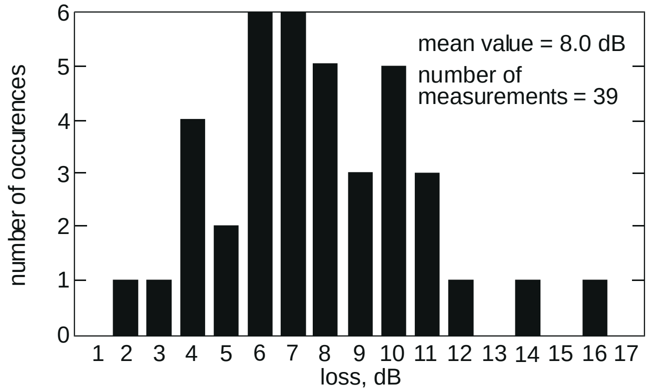

Fig. 26 - Spread of building penetration losses.

and the results have been reported in Ref. 7. Most of these were typical domestic houses located in suburban areas. During the high-power experiments, a further 13 buildings have been measured. These concentrated on buildings in urban and dense urban areas.

The first set of measurements found an average building penetration loss to ground floor locations of 7.9 dB. As expected, it was found that signal levels upstairs in houses were higher. The measurements concentrating on houses and basement flats in built-up areas were expected to find a higher building loss; however an average value of 8.3 dB was measured. This was not significantly different from the earlier measurements. On reflection, the absence of change with degree of ground clutter is believable as the clutter loss will usually affect both the signal level outside and inside the house. The spread of building penetration losses measured is shown in Fig. 26.

Within the house, the average standard deviation of the signal variation over the measurements taken on the ground floor was found to be around 4 dB.

5.5.2 Subjective requirements for reliability of coverage

One of the tasks identified earlier was to investigate the subjective coverage requirements for portable reception in buildings. That is, to make some measurement of the percentage of locations within a building that must be covered before, on average, a listener will find the service acceptable. Such a figure could then be incorporated into coverage criteria.

Investigating this subject is fraught with difficulties. As with all subjective testing the problem of justifying terms such as what constitutes a service is difficult. The problem is further exacerbated, as not only are a number of people sampled, but also the opinion of each of them is sought in a different house. Finally, their listening habits, expectations and uses of radio receivers are often different.

As a first step in investigating this issue, at the same visit as making penetration loss measurements, the opinion of the owner of the house was sought as to the minimum acceptable coverage in their house. An

attenuator was added in the signal path between the receiving antenna and the receiver. This was adjusted until the house was just deemed to be served. The percentage of locations in the room for which the audio did not have scale factor CRC errors was then measured.

The results suggest that around 80% of locations should be served within a room before it is deemed to be served. However, this percentage varied greatly from house to house or person to person. It appears that this is because there are relatively few places where people are prepared to put receivers.

The second important point was that, once a satisfactory location had been found, it was very important that it should stay satisfactory as people moved around the room and other channel disturbances occurred.

6. DISCUSSION

The first results from the network of transmitters around London have demonstrated a number of interesting properties of the EUREKA DAB system. They have confirmed, over a large number of measurements made in many different areas, that the frequency diversity inherent in the system provides a significant reduction in the amount of signal variation. This is an important property of any digital system designed to serve mobile and portable receivers, as a very high level of availability for the system is required.

The results have also provided an important validation of the performance of the system, as good audio reception has been found over the area expected from predictions and simulations of the system. This indicates that the system, and the first equipment built to the system specification, is operating as expected.

Whilst detailed analysis of the measurements obtained when several transmitters are simultaneously received is still in progress, the results show significant improvements in coverage, even when there were relatively large differences in the median signal levels from the different transmitters. This supports earlier experiments, which have shown the reduction in the amount of signal variation when multiple signals are received and the consequent reduction in errors in the received data stream[8].

An interesting consequence of this work is that satisfactory reception has been found in most of the London area using only relatively-low transmitter e.r.p.s.

The results have provided data which is being used to refine the algorithms and methods used for coverage prediction. This is an important input at a time when the BBC is planning the locations and e.r.p.s of the network of transmitters which will be used to serve the United Kingdom with DAB services. The experience in the development of these techniques is showing that the experimental measurements have a major impact on the accuracy of the coverage prediction algorithms, which require significant modifications of the techniques normally used for analogue broadcast signals.

However, there are still a number of important topics which are being investigated using the network. Examples are:

- Experiments are being performed to measure the correlation between signals from different transmitters. This is an important measure for quantifying the benefit that occurs from the spatial diversity (which happens when signals from more than one transmitter are received simultaneously).

- Different solutions for local-area broadcasting using the system will be investigated.

- More accurate quantification of the magnitude and effect of long-distance interference from transmitters is needed. Such work is, of course, time consuming, as high levels of interference only occur for a small percentage of time and long measurement periods are required to achieve statistically significant results.

7. CONCLUSIONS

The Report has described the first results from field tests of the EUREKA DAB system. These tests are being conducted in and around London and use four, 1 kW, VHF transmitters operating as a single-frequency network.

The results show a wide area coverage from these transmitters which is in reasonable agreement with experimental predictions. This indicates that the current equipment, built to the EUREKA DAB specification, is operating in the way that would be expected from theoretical studies and simulation.

The results also provide quantitative values which can be used for coverage prediction and for international co-ordination of services. These values are similar to those measured in early work.

Finally, the performance of the system demonstrates a

number of the benefits of the EUREKA DAB system for mobile and portable reception. In particular, the reliability that can be achieved without needing very high-power transmitters; this results from the frequency diversity which is inherent in the system and the spatial diversity which can be obtained if more than one transmitter radiates the same signal at the same frequency. All this has given the BBC the confidence to proceed with plans towards implementing a UK national single-frequency DAB network for its national programme services.

8. ACKNOWLEDGEMENTS

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